A STUDY ON THERMAL CHARACTERISTIC OF SOLID AND HOLLOW GLASS MICROSPHERES FILLED POLYPROPYLENE COMPOSITES

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A STUDY ON THERMAL CHARACTERISTIC OF SOLID AND HOLLOW GLASS MICROSPHERES FILLED POLYPROPYLENE COMPOSITES

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by

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Certificate of Examination

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We the below signed, after checking the dissertation mentioned above and the official record book(s) of the student, hereby state our approval of the dissertation submitted in partial fulfillment of the requirements for the degree of Master of Technology in Mechanical Engineering at National Institute of Technology Rourkela. We are satisfied with the volume, quality, correctness, and originality of the work.

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May 28, 2016

Supervisor's Certificate

This is to certify that the work presented in this dissertation entitled "*A STUDY ON THERMAL CHARACTERISTIC OF SOLID AND HOLLOW GLASS MICROSPHERES FILLED POLYPROPYLENE COMPOSITES"* by **''*BUTUNATH MAJHY*''**, Roll Number **214ME3314**, is a record of original research carried out by him under my supervision and guidance in partial fulfillment of the requirements for the degree of ***Master of Technology* in *Mechanical Engineering***. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

Prof. Alok Satapathy

DEDICATED

TO MY PARENTS

Declaration of Originality

I, *Butunath Majhy*, Roll Number *214ME3314* hereby declare that this thesis entitled *A STUDY ON THERMAL CHARACTERISTIC OF SOLID AND HOLLOW GLASS MICROSPHERES FILLED POLYPROPYLENE COMPOSITES* presents my own work carried out at National Institute of Technology, Rourkela as a postgraduate student in engineering and to the best of my knowledge, it does not contains any material written by another person or previously published and not any material presented by myself further award of any other degree at any other institution or at NIT Rourkela. It is explicitly acknowledged in the thesis for any contribution made to this research by others and with whom I have worked at NIT Rourkela or elsewhere. Works of other authors cited in this thesis have been duly acknowledged under the section "References". I have also deposited my original research records to the scrutiny committee for my evaluation of thesis.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

MAY 28, 2016

Butunath Majhy

NIT Rourkela

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Finally, I want to thank my parents who have been a source of strength and support for me. Their teaching and sayings continuously guided me to achieve the excellence in my work and pushed me to think critically and never settle for anything less than my best. At last, I thank ***Almighty God*** for giving me an opportunity to work in such an environment with such good and knowledgeable people around.

MAY 28, 2016 *Butunath Majhy*

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ABSTRACT

The report regards the heat transfer in the polymer composites of solid glass micro-spheres (SGS) or hollow glass micro-spheres (HGS) filled with polypropylene (PP). The net effective thermal conductivities (K_{eff}) of the polymer composites of PP and SGS or PP and HGS are estimated by analytical integral approach and its result was compared with ANSYS model and existed theoretical models. It was observed that the effect of thermal insulation in hollow glass spheres filled polypropylene composites is more than the solid glass spheres filled polypropylene composites and the net effective thermal conductivity (K_{eff}) is linearly decreases with increases of volume fraction (φ_f) of filler and then decreased somewhat with increasing filler diameter. It was found that the analytical model is very close to ANSYS model and existing analytical models. Furthermore, the net effective thermal conductivity (K_{eff}) of the three dimensional (3D) ANSYS model is lesser than two dimensional (2D) ANSYS model i.e. 3D ANSYS model is fairly closer with the experimental data than 2D ANSYS model.

With improved insulation capability and light weight of composites, the solid glass micro spheres (SGS) and hollow glass micro-spheres (HGS) inserted polypropylene composites can be utilized in areas such as building materials, aviation industry and space flight, insulation boards, thermo flasks, food containers etc.

Some other properties changed like enhanced wear resistance, increased reflective index, decreased coefficient of thermal expansion and increased the glass transition temperature.

***Index Terms* — Polymer composites, PP, SGM, HGM, volume fraction, Thermal characteristic.**

Contents

Chapter 1

1.1 Introduction

1.1.1 Background and Motivation

Now a day, polymer composites are the most replacing materials in different structural and engineering utilizations. They have been widely utilized industrial applications, space craft uses due to their low density, good specific strength, good modulus and good wear resistance (Hutchings, 1992). Due to they have less weight, those are most preferable material in sensitive weight utilizations. Sometimes their use restricted in general applications due to their high cost.
By using easily available and low cost fillers having improve properties, they can decrease the overall cost of components (Unal et al., 2003; Kranthi and Satapathy, 2010;). Metal particulates or ceramic like hard particulates are used now a day, due to their thermal resistance and good wear resistance of the polymer (Gregory et al., 2003). Addition of such reinforced fillers in polymer materials for the use of domestic applications is mainly focused at the cost decrease and the stiffness betterment (Rothon, 1999). Many researchers (Nayak et al., 2010; Suresha et al., 2010; Bahadur & Schwartz, 2001 and Mohan et al., 2011) have presented that the thermal resistance and wear resistance is improved of polymers due to addition of filler particulates.

In last two decades, it has been emerged as subject of most research by ceramic mixed polymer composites. In this current work, my objective is to explore the potential of Solid glass micro spheres (SGM) and Hollow glass micro- spheres (HGM) as are filling materials in polypropylene polymer composites and investigate its thermal characteristics of result composites. In this work an attempt has been taken to find a useful use of SGM and HGM as particulates filler in polymer composites for the development of thermal resistant composites.

Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) contain outer stiff glass, by which we got some useful properties as light weight, low thermal conductivity, high strength, wear prevention and resistance to salt or organic solvent . Due to having these properties , SGM and HGM have been used for different applications in polymer composites (Khamis and Kim, 2001; Liang, 2002; Zhao, 2007; Liang, 2005). They have other properties like low moisture absorption, high specific compressive strength and high thermal stability, due to these properties they more suitable for marine and aeronautical applications (Wouterson et al., 2004; Khamis &Kim, 2001; Nagorny & Gupta, 2006, Plubrai & Kim 2004).

Solid glass micro spheres (SGM) and hollow glass micro spheres (HGM) have require able thermal properties with high softening point (glass transition temperature), low coefficient of thermal expansion, high resistance to water attack, acids attack, halogens, salt and organic solvents.

1.2 Composite Materials

It is combination of two or more materials having different chemical and physical properties. But the composites will have different properties than the parent materials. Generally composites have improved property than the parent material.

1.2.1 Types of Composite Materials

Composites are classified into different group based on matrix material
a) Metal Composites
b) Ceramic Composites
C)Polymer Composites

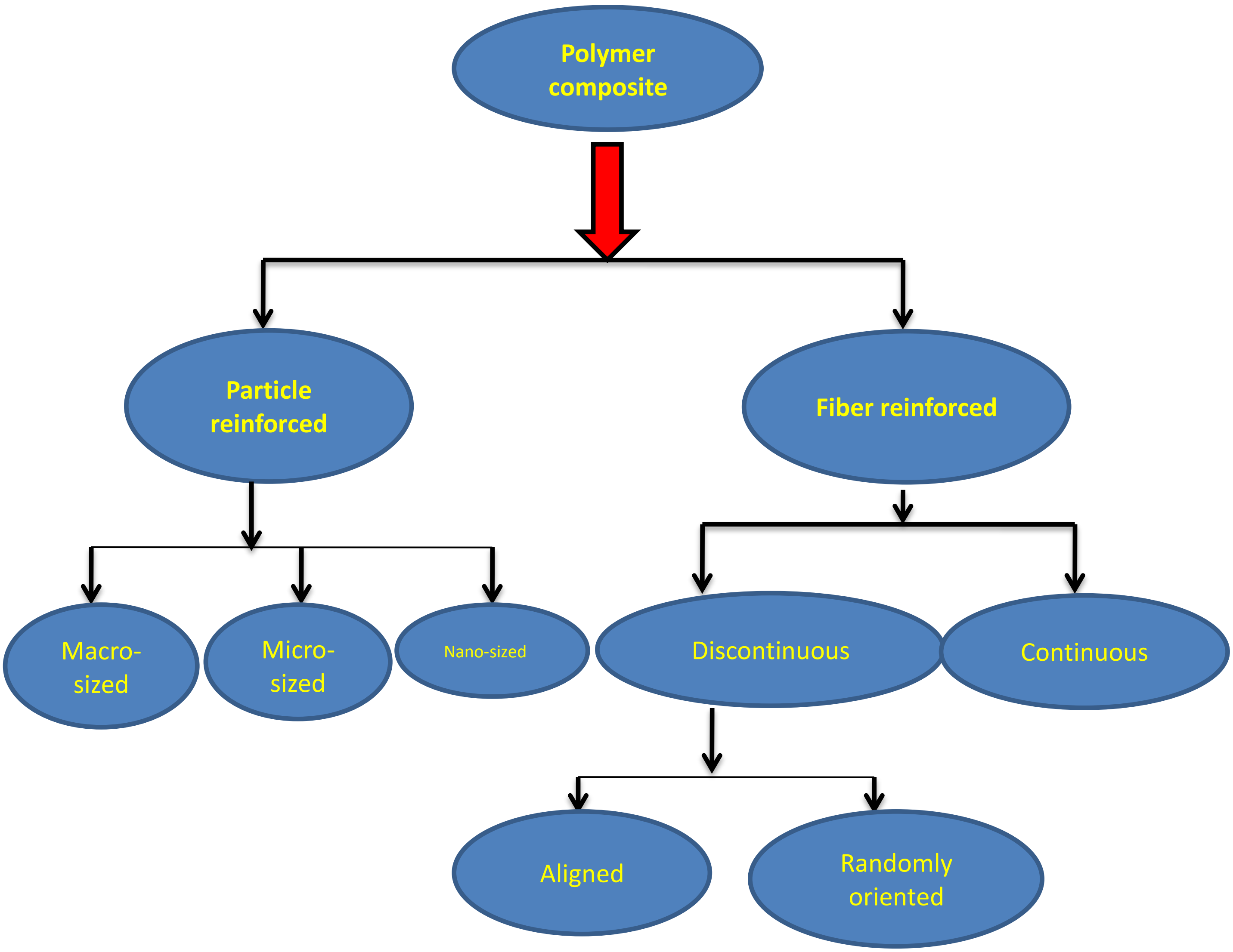


Fig. 1.1 Classification of composites based on reinforcement type

CHAPTER 2

2.1 LITERATURE REVIEW

YEAR	NAME	MATERIAL	ANALYSIS	METHODS
2015	Long Ngo Byon	Generalised, Hetrogenious (Nano particles & Fibers)	K_{eff}, 3-D, Filler volume fraction, Consider contact resistance	Finite difference method
2015	N. Burger	Epoxy & Graphite (Fiber Graphite)	K_{eff}	Experiment
2014	H. Haddad W. Leclerc	Alumina	K_{eff}	C++
2015	Ya-Ling He Tao Xie	Nano porous Silica, Aerogel & (Fiber glass, asbestos, rock wool)	K_{eff} (insulation) Conduction & Radiation	Experiment
2015	Jan-Jun Gou Wen-Quan Tao	Carbon fiber Nano particles 4-Directional	K_{eff} 3-D	FEM
2015	Biao Xie Zhi-ming Xu	Phase change material Aluminium (Honeycumb)	K_{eff} Stress Latent heat	Analytical Experimental
2015	Cheng-Hung Hung Hsuch-Min Hsu	Fillers of two conductive bodies	K_{eff}	CFD ACE LMM

YEAR	NAME	MATERIAL	ANALYSIS	METHODS
2014	Laurent Pilon Aditya Kumar	Generalised Nano Particles	K_{eff} 1-D Filler volume fraction Contact resistance	Numerical, Experimental
2015	Tarek Mabrouki	Cupper Diamond	K_{eff} Interfacial resistance	Finite element method
2015	Yibing Cai Qufu Wei	Capric-Laurix-Palmatic Acid (Phase change material) SiO_2 (Nano fiber)	K_{eff}	Experiment
2015	Weixiong Wu Chenzhun Liu	Paraffin & Expanded graphite	K_{eff}	Experiment
2013	Jae-kon Lee Jin-Gon Kim	Laminated carbon fiber	K_{eff}	Experimental
2015	Animesh Dutta	P-type & N-type Semiconductor	COP Thermal Efficiency	Effective Medium Theory
2015	V. I. Kushch A. S. Belyaev	Spherodical Particle	K_{eff} Imperfect Interfaces	Analytical

2.1.1 Knowledge Gap in Earlier Investigations

Notwithstanding various exploration works reported previously, there is a colossal learning crevice that requests a very much arranged and precise examination here of particulate filled polymer composites. A thorough audit of the distributed writing uncovers that:

- Most of works have done on solid glass micro spheres (SGM) but very less work have done on hollow glass micro spheres (HGM).
- Most of the investigations are aimed at enhancing the heat conductivity of the polymer by adding conducting filler rather than attempting to improve its insulation capability.
- Most of the works reported on thermal conductivity of particulate filled polymers are experimental in nature and reports available on numerical and analytical models are few.

2.1.2 OBJECTIVE OF PRESENT WORK

1. Explore the potential of Solid glass micro spheres (SGM) or Hollow glass micro spheres (HGM) as are filler materials in polypropylene polymer composites.
2. A theoretical model is developed for the estimation of Effective thermal conductivity of particular filled reinforced composites.
3. Estimation of effective thermal conductivity of such particulate filled polymer composites using Finite element method (FEM).
4. Fabrication of different sets of PP composites filled with SGM or HGM.
5. Validation of the proposed theoretical analytical model by comparing with ANSYS result of FEM model and Existing theoretical models.
6. Comparing 1-D heat transfer with 3-D heat transfer.
7. SEM micrographs of samples.
8. Exploring the possibility of using these composites in suitable application areas.

2.2 MATERIALS AND METHODS

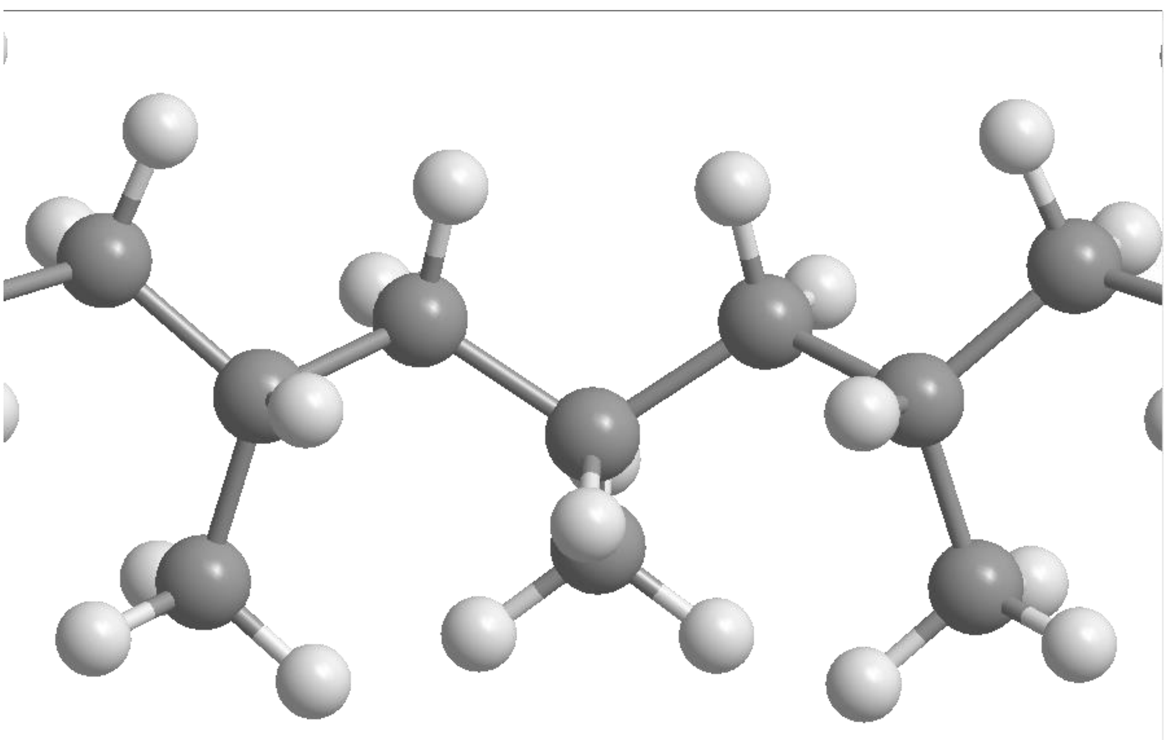
This part depicts the materials and techniques utilized for preparing and describing the composites under scrutiny. It displays the subtle elements of the tests identified with the physical, mechanical, smaller scale auxiliary, warm and dielectric portrayal of the readied particulate filled polymer composite examples.

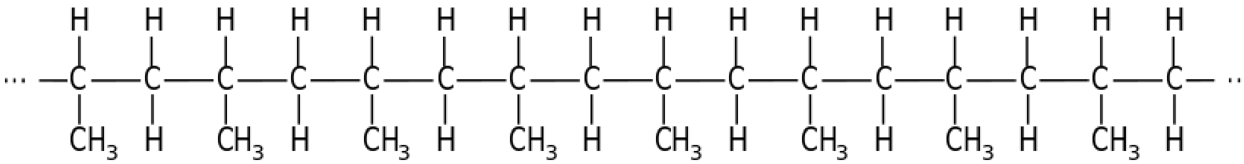
MATERIALS

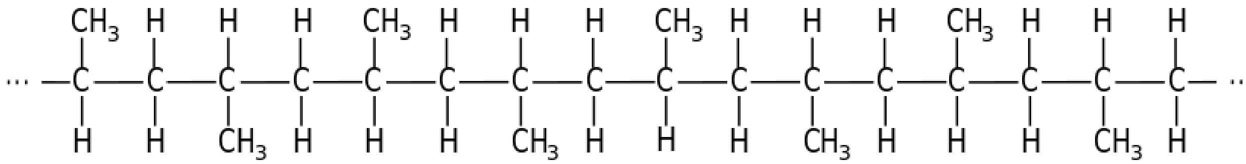
Matrix Material

The material which is used as base material is called as matrix material. It has maximum percentage of volume in composites. Composite's property mainly depends on matrix material. Matrix material is selected according our requirement property. Matrix material should have ability to absorb other material. Here I am using polypropylene as matrix material. It is a thermoplastic material of carbon and hydrogen compound.

Polypropylene







Properties of polypropylene

Properties	Values
Density	.946 gm/cc
Thermal Conductivity	.2 W/m-K
Compressive strength	60-70 Mpa
Tensile strength	30-40 Mpa
Micro hardness (Rockwell)	80-102
Thermal coefficient of expansion	$100 – 150 * 10^{-6}$
Glass transition temperature	100^0 C

Filler Materials: (Solid glass micro spheres)

Micro sized hollow glass micro-spheres (HGM) and solid glass micro spheres (SGMs) of one average sizes (100 μ m,) purchased from NICE Ltd. was used as the reinforced filler material in this research work.

Some important properties of glass microspheres

Properties	Values
Density	1.50 gm/cc
Thermal conductivity	0.02 W/m-K
Compressive Strength	248.0 MPa
Tensile Strength	56.0 MPa
Micro hardness	6.845 GPa
Electrical conductivity	$0.109 * 10^{-16}$ S/cm
Glass transition temperature	400K

Hollow glass microspheres

2.2.1 Physical Characterization

Density and voids volume fraction

Density is the most important property of the composites, total density of composites depends on both the densities of filler material and matrix material density and also it depends on the weight percentage of both filler and matrix. Density of composites also depends on volume of voids because in voids air will trapped and its density is very low so overall density will decreases by increase in volume fraction of voids. The theoretical density **(ρ_{ct})** value of composites is determined by equation given by Broutman and Agarwal.

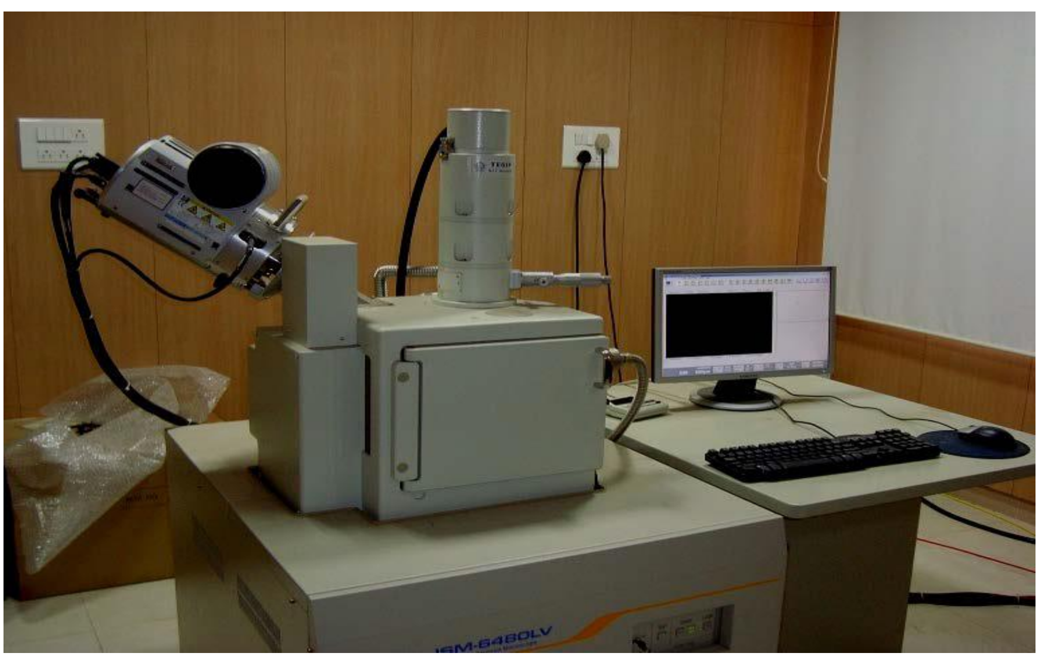
$$\rho_{ct} = 1/ ((w_f/\rho_f) + (w_m/\rho_m))$$

where, *w* represents weight fraction and ρ represents density. The suffixes *f* is used for filler and *m* for matrix. By the help of Archimedes principle actual density (ρ_{ce}) of composites is determined or by the help of. the water displacement technique (ASTM D 792-91).
The voids volume fraction (V_V) is calculated by using the below equation of the composites:

$$V_v =(\rho_{ct} - \rho_{ce})/\rho_{ct}$$

Scanning electron microscopy (SEM)

Scanning electron microscope is used to show the micro structure of composites with high resolution. From the SEM image we can predict the volume fraction of voids and internal correlation between filler & matrix. We are using the Scanning electron microscope of model JEOL JSM-6480 LV as shown in below. With the help of silver paste the specimen is mounted on stubs. Before the picture was taken a thin film platinum is vacuum evaporated on the sample for increasing the penetration of light.



2.2.2 Mechanical Characterization

Micro-hardness

Leitz micro-hardness tester is used to measure the micro- hardness. Below Figure shows the Leitz micro hardness tester. A diamond indenter pressed into the composite material having a load *F*. The diamond indenter is like a pyramid having nose angel of 136^0. The indentation marked on the composite face is measured by the two diagonals X and Y and then a arithmetic logarithmic will take. In this study, the load taken is *F*= 0.2454 N and Vickers hardness number is given below.

$$\mathbf{H_v = 0.1889\ F/L^2}$$

Where, L= (X + Y)/2

where, *F* is the applied load (N), *X* is the horizontal length (mm) and *Y* is the vertical length (mm) and *L* is the diagonal of square impression (mm). The composite hardness is expressed in GPa.

Leitz micro hardness tester

Compressive strength

Universal Testing Machine *Instron 1195* shown on below (Figure) is used to test compressive strength in uni-axil direction. The compressive load is applied until specimen shows signs of failure. A standard specimen is used to test according to ASTM 695.

Tensile strength

A uni-axial tensile in nature load is applied at both the ends. This test is carried out in the same universal testing machine Instron 1195. A stress strain graph is plotted on a graph paper with the help of pencil according to movement of ends. Load will apply up to the breaking point. From the stress strain curve we will calculate the tensile strength with the help of Young's modulus (E).

Universal testing machine *Instron 1195*

2.2.3 Thermal Characterization

Thermal Conductivity:
Unitherm™ Model 2022 is generally used to measure the thermal conductivity. It is used for various material like glasses, polymers, ceramics, rubbers, composites having organic or metallic fillers. It is also used for measuring the thermal conductivity of Fluid or semi fluid like substances.

Between two polished surfaces the testing material is held under a constant compressive load.

The heat flows through the sample from the top surface to bottom surface and prodes a temperature gradient. After temperature become equilibrium, the difference in temperature is calculated across the sample and output from the transducer of heat flow.

By the help of these values and taking thickness of sample into consideration we will calculate the thermal conductivity.

Thermal Conductivity Tester *Unitherm ™ 2022*

Thermal Mechanical Analyzer

The temperature at which a material is changed from solid like structure to a rubber like structure is called glass transition temperature. At this temperature the material start to change its internal structure so its properties also changes at this temperature. The material losses it’s structural stability at this temperature. It is very much important to measure the glass transition temperature and by the help of this temperature operating temperature of material is determined. Generally the glass transition temperature is measured by Perkin Elmer DSC-7 Thermal Mechanical Analyzer which is shown below fig.

Firstly the nitrogen gas is purged on thermal mechanical analyzer sample. A standard sample will take for test. The test sample is heated from 30 to 150^0C by supplying a heating rate of 5^0C/min. Two heating scans are used for every measurement. Any moisture and possible internal stresses during curing are removed by first heating scan. Coefficient of thermal expansion and glass transition temperature was measured by second heating scan.

Perkin Elmer DSC-7 Thermal Mechanical Analyzer

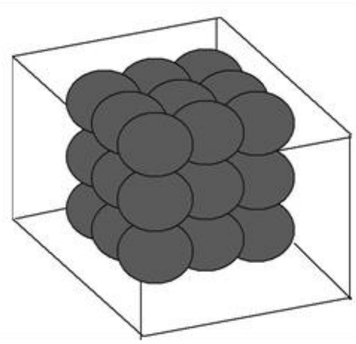
Chapter 3

3.1 Methodology and model description

METHODOLOGY

The calculation of actual properties of the composites is of main important for better design and utilization of the Composite materials. Micro structural properties of composites are essential thing which affect the effective properties of composites. Micro structural means size, shape, orientation and spatial distribution of embedment of matrix.

Schematic presentation of solid micro glass spheres embedded in a polypropylene matrix having a regular arrangement is shown in below fig. The boundary conditions and the heat flow direction for conduction is shown in the below fig. Here the temperature at top face is 100^0c, convection heat transfer occurs at the bottom face having convection heat transfer coefficient is 25W/m^2-K and other four faces are insulated. The temperatures on other boundaries and at inside domain are not arrested.



GOVERNING EQUATIONS

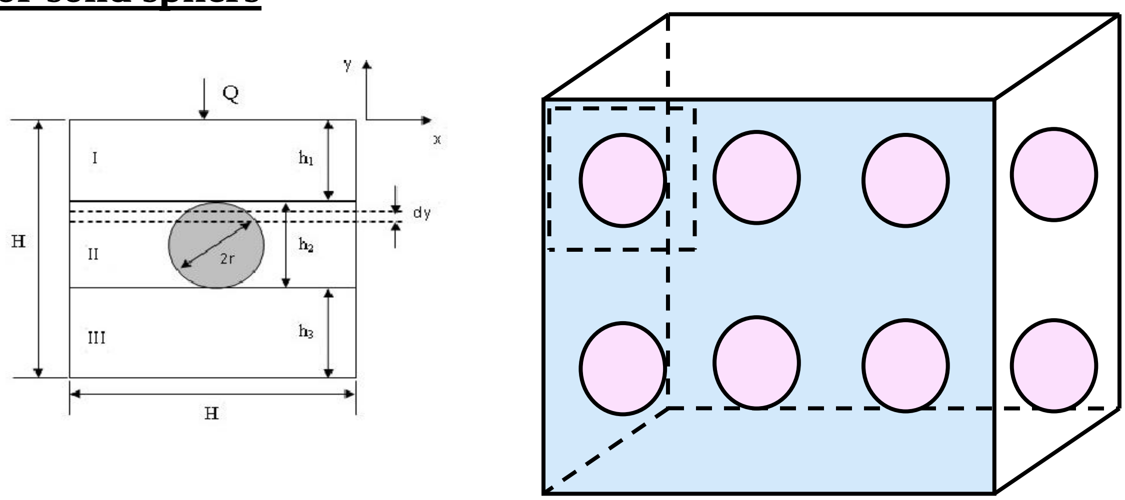
Analytical model for determination of the net effective thermal conductivity (K_{eff})

Values of the net effective thermal conductivity of the above PP composites of different filler percentage have been estimated analytically by using the Eqn. given below. It is derived on one dimensional (1D) conduction model by integral approach. The assumptions that have taken to solve this Eqn. are

- Heat flows only one direction i.e. other four faces are insulated.
- Both the boundary surfaces are at uniform temperatures throughout the surfaces.

- Heat flows perpendicular to the surfaces.
- Composites are homogeneous in macroscopically.
- Both filler and matrix isotropic in locally.
- Contact resistance between matrix and filler material neglected.
- No void inside the composites is assumed.
- Uniformity in distribution of filler inside the matrix in a periodic manner.

For solid sphers



Above Figure represents the 3-D view of particulate filled composite model and an element is taken is taken into consideration for further study the heat transfer behavior consisting of a miniature cube with a particle is in the center of it.

- ❖ The element is subdivided into three parts where Part I and part III represents the only polymer and the thickness is h_1 and h_3 where $h_1 = h_3 = (H-2r)/2$.
- ❖ Part II is the combination of the polymer and microsphere and the thickness is h_2 ($h_2=2r$).
- ❖ The equivalent thermal conductivity of whole composite is calculated by using the specific equivalent thermal conductivity theory.

Because of the linear distribution of temperature, the average thermal conductivity of each section may first be obtained:

$$Q = KA \frac{\Delta T}{\Delta X}$$

Thermal resistance

$$R = \frac{dx}{KA}$$

For part I and III

$$K_1 = K_3 = \int_0^{h1} K\,p\ \frac{dy}{h1} = \mathrm{Kp}$$

For part II

$K_2 = \frac{Qp + Qf}{\left(\frac{dT}{dy}\right)A} = \frac{Kp\ Ap}{A} + \frac{Kf\ Af}{A}$

Now integrating it over the complete thickness, we will get

$K_2 = \int_0^{h2} \left(\frac{KpAp}{A} + \frac{KfAf}{A}\right) dh$ / h_2

$= \int_0^{h2} \frac{\left(\frac{KpAp}{A}\right)dh}{h2} + \int_0^{R} \frac{Kf}{RA}\ \pi\ (2Rh - h^2)dh$

$= \frac{KpVp}{h2A} + \frac{\pi Kf}{RA}\ [R^3 - R^3/3]$

$= \frac{KpVp}{h2A} + \frac{2\pi Kf R^3}{3RA}$

$= \frac{KpVp}{h2A} + \frac{VfKf}{h2A}$

Thermal Resistances are

$R_1 = R_3 = \frac{h1}{KpA}$

$R_2 = \frac{h2^2}{KpVp+KfVf}$

$K_{eff} = \frac{H}{(R1+R2+R3)A}$

$K_{eff} = H/(\frac{h1}{KpA} + \frac{h2^2}{KpVp+KfVf} + \frac{h1}{KpA})A$

$K_{eff} = H/(\frac{2h1}{Kp} + \frac{h2^2A}{KpVp+KfVf})$

From fig $h_1 = \frac{H-2r}{2}$, $h_2 = 2r$

So $K_{eff} = H/(\frac{H-2r}{Kp} + \frac{4r^2A}{KpVp+KfVf})$

But $\emptyset f = \frac{Vf}{Vc} = \frac{4\pi r^3}{3H^3}$

So $H = r\sqrt[3]{(4\pi/3\emptyset f)}$

So $K_{eff} = \frac{r\sqrt[3]{(4\pi/3\emptyset f)}}{\frac{r\sqrt[3]{(4\pi/3\emptyset f)}}{Kp} - \frac{2r}{Kp} + \frac{4r^2A}{KpVp+KfVf}}$

$K_{eff} = 1/(\frac{1}{Kp} - \frac{2}{Kp\sqrt[3]{(4\pi/3\emptyset f)}} + \frac{1}{\sqrt[3]{(4\pi/3\emptyset f)}}\left\{\frac{4rA}{KpVp+KfVf}\right\})$

For hollow spheres

$A_f = 2\pi (\sqrt{2Rh - h^2}\ ) t$

Total cross section = $\int_0^R 2\,\pi\,(\sqrt{2Rh - h^2}\ )\ t\ dh$

$= \int_0^R 2\,\pi\,(\sqrt{-(\ h^2 - 2Rh}\ )\ t\ dh$

$= \int_0^R 2\,\pi\,(\sqrt{-(\ h^2 - 2Rh + \ R^2 - R^2}\ )\ t\ dh$

$= \int_0^R 2\,\pi\,(\sqrt{(\ R^2 - (h-R)^2}\ )\ t\ dh$

Let $h - R = Z$

$dh = dZ$

$= 2\pi t \int_{-R}^{0} 2\,\pi\,(\sqrt{(\ R^2 - Z^2}\ )\ t\ dZ$

$= 2\pi t \left\lfloor \frac{Z}{2}\sqrt{(\ R^2 - Z^2} + \frac{R^2}{2}\ sinh^{-1}\frac{Z}{R} \right\rfloor {}^{0}_{-R}$

$= 2\pi t\ (\frac{R^2}{2}\,sinh^{-1}(0) - \frac{R^2}{2}\ sinh^{-1}(-1))$

$= .88\ \pi t R^2$

$K_2 = \frac{KpVp}{h2A} + \frac{1.762}{h2A}\ K_f \pi t R^2$

Let, $V_f = 1.762\ \pi t R^2$

$K_1 = K_3 = \int_0^{h1} K\,p\ \frac{dy}{h1} = Kp$

$K_{eff} = \frac{H}{(R1+R2+R3)A}$

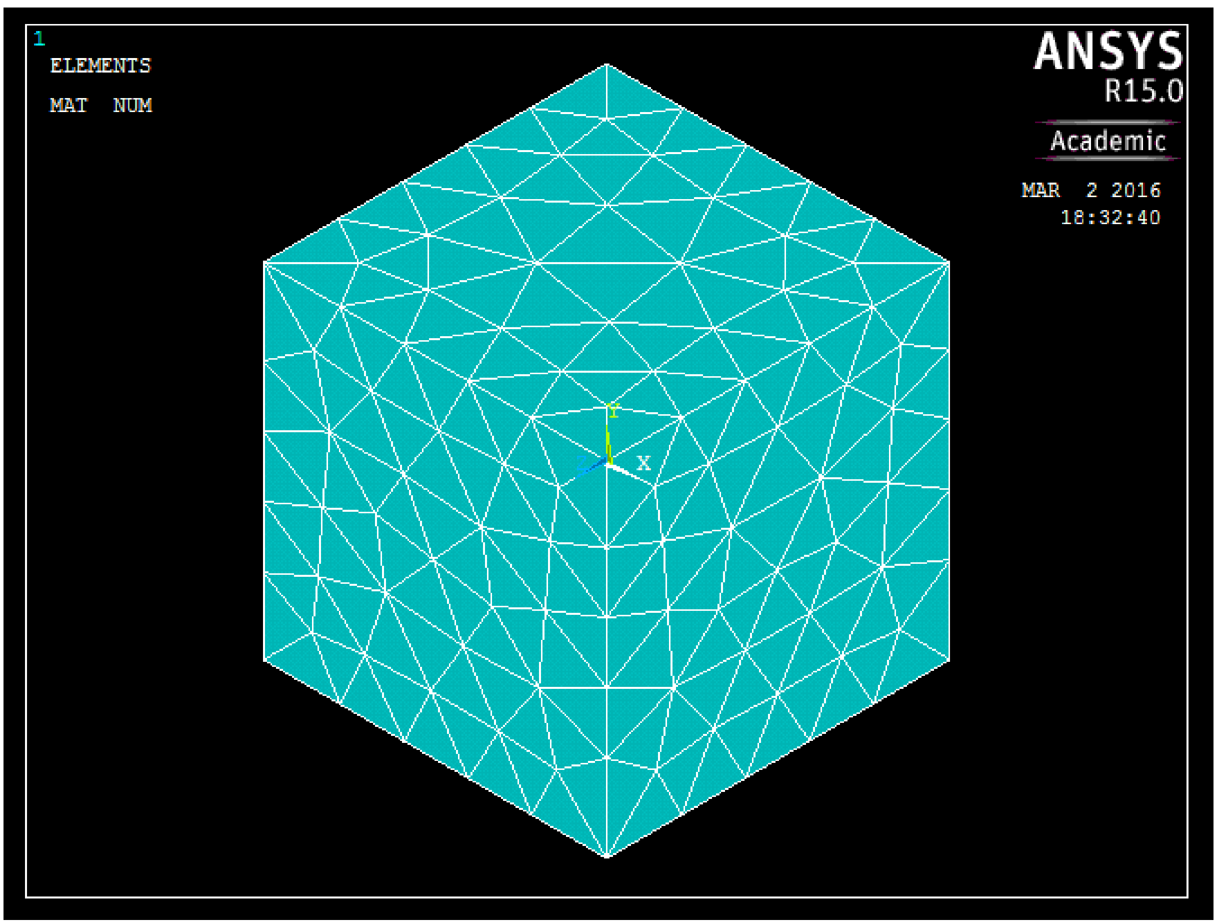
$K_{eff} = H/(\frac{h1}{KpA} + \frac{h2^2}{KpVp+KfVf} + \frac{h1}{KpA})A$

Chapter 4

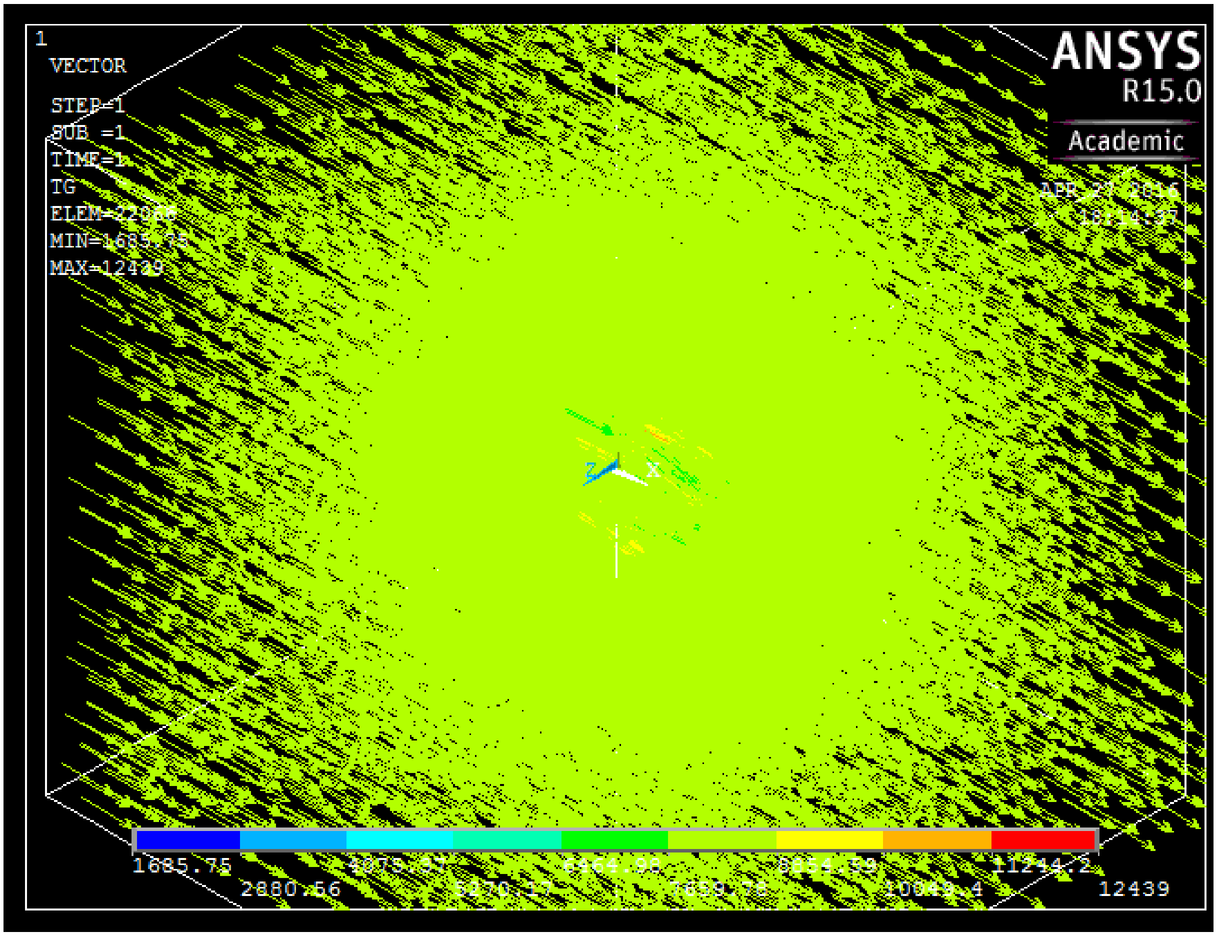
Results and Discussion

NUMERICAL SIMULATION

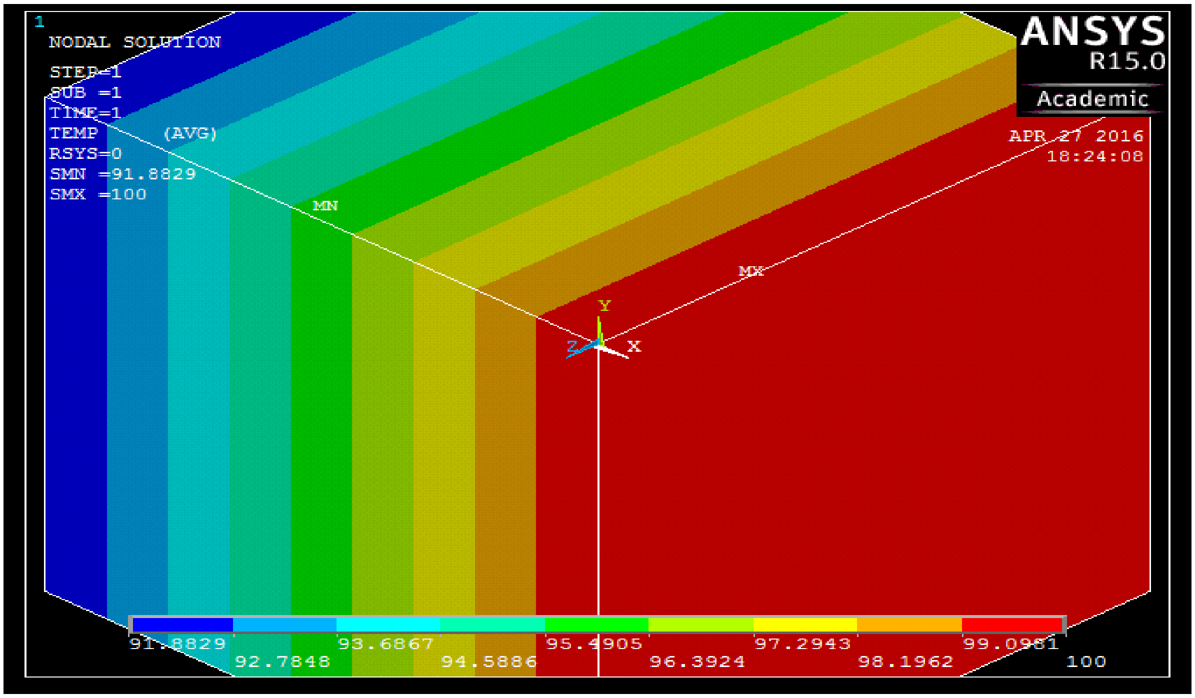
Net Effective thermal conductivities (K_{eff}) of polypropylene and Solis glass micro spheres composites are estimated numerically by help of spheres in cube model. Different temperature profiles have been obtained from analysis of FEM of composites of polypropylene and SGM of 100 μm size having different volume fractions .05%, .42%, 1.41%, 3.35% and 5.23% as shown below.



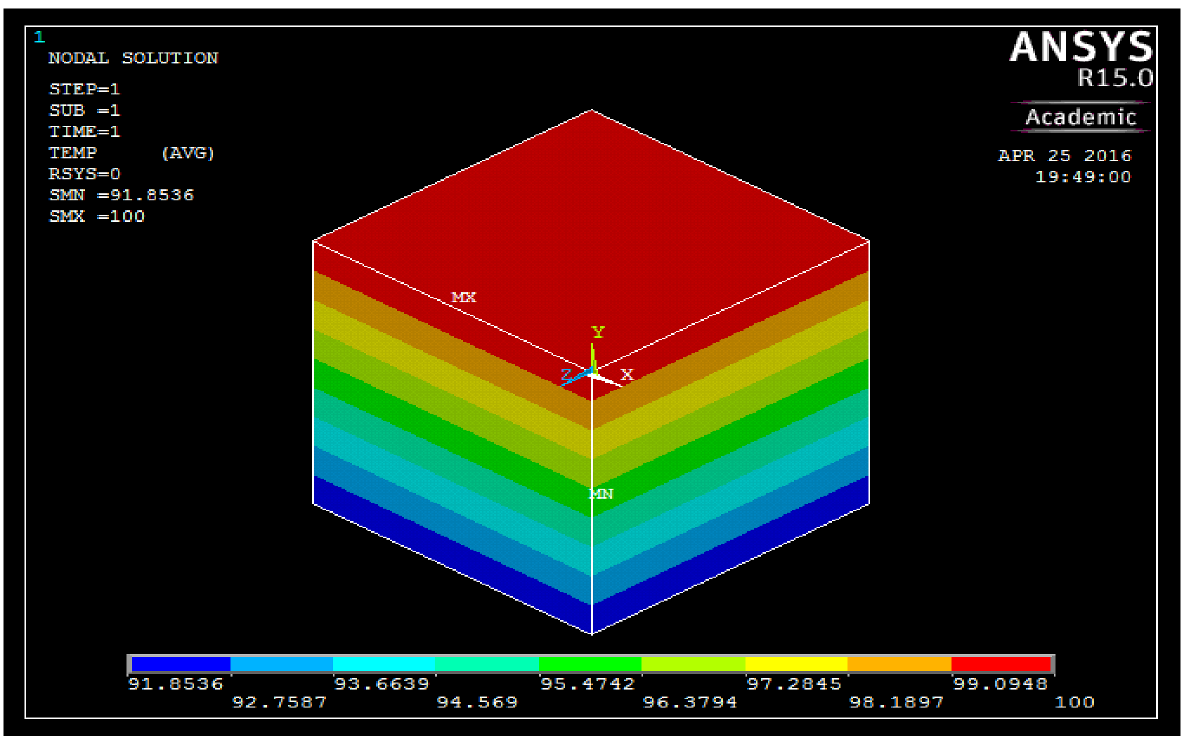
Meshing for .05% filler solid



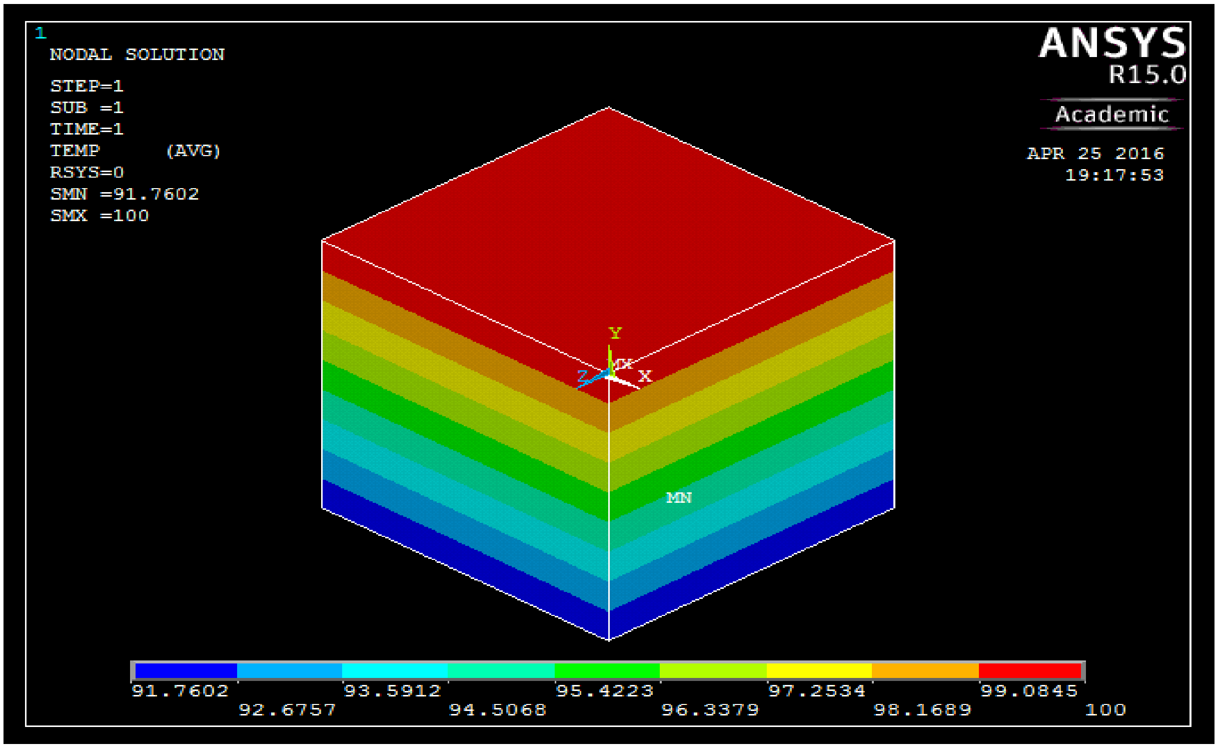
.05% hollow filler temp counter



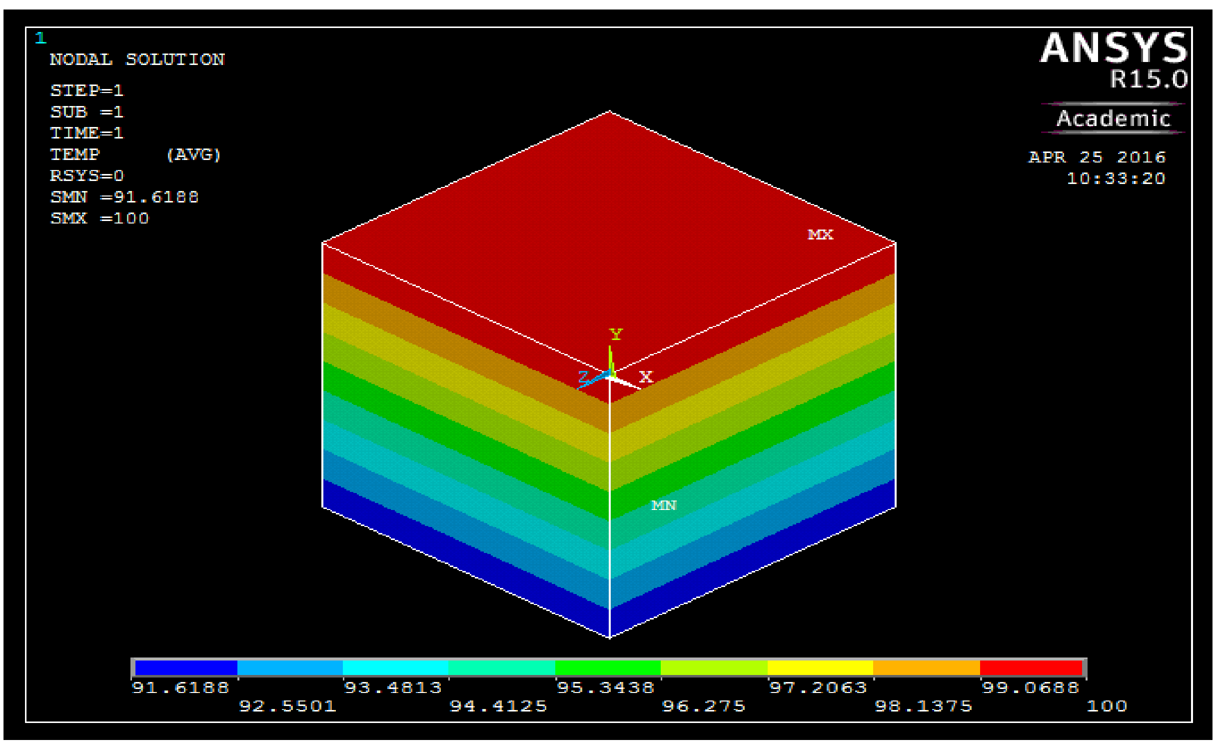
0.05% filler solid



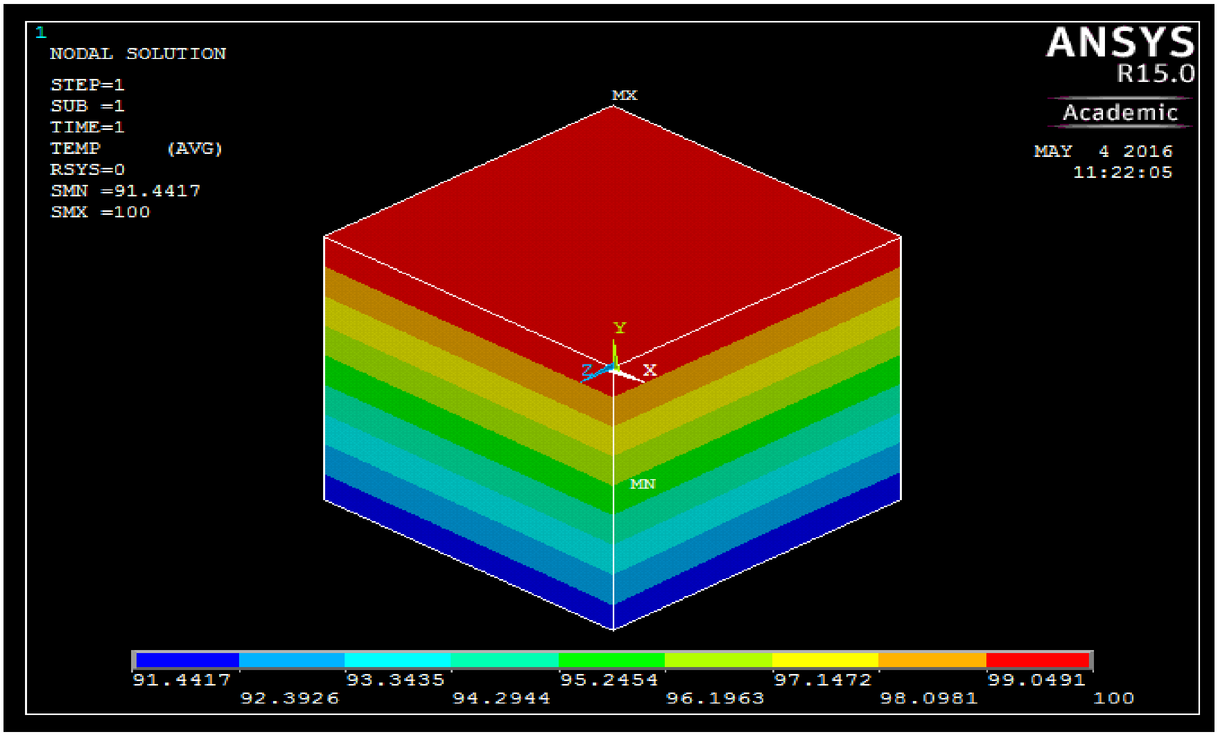
0.42% filler solid



1.41% filler solid

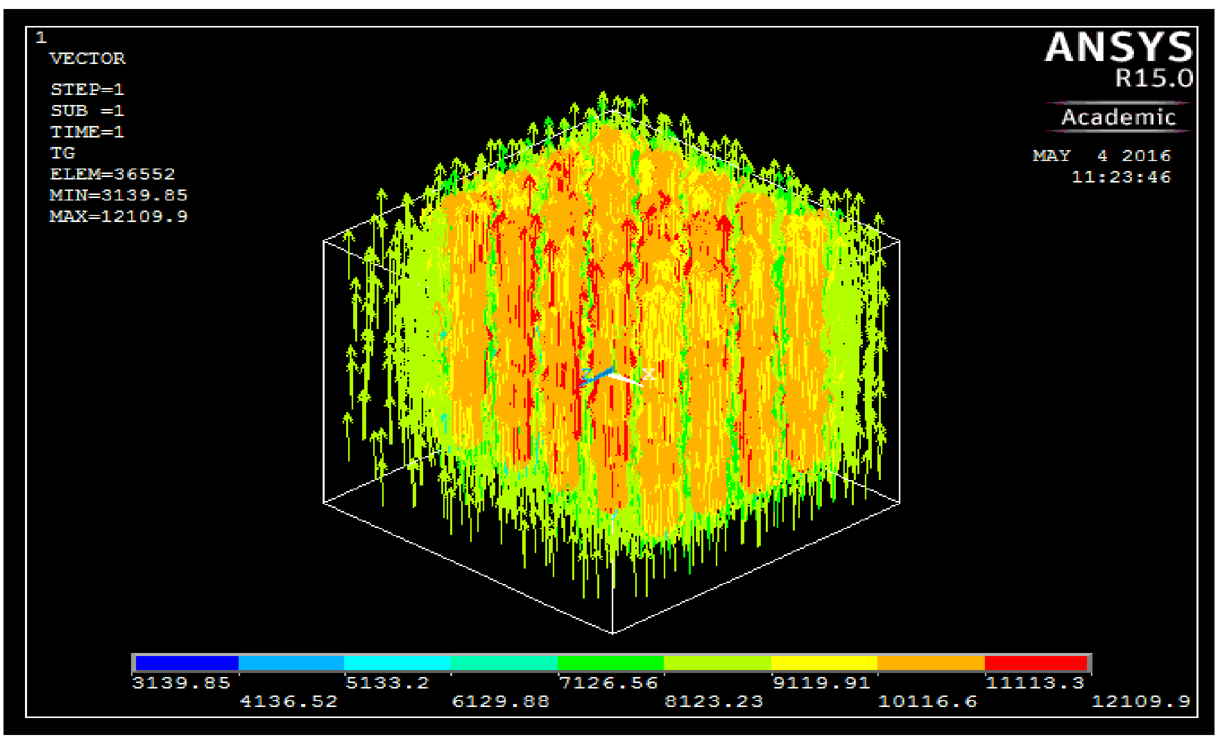


3.35% filler solid



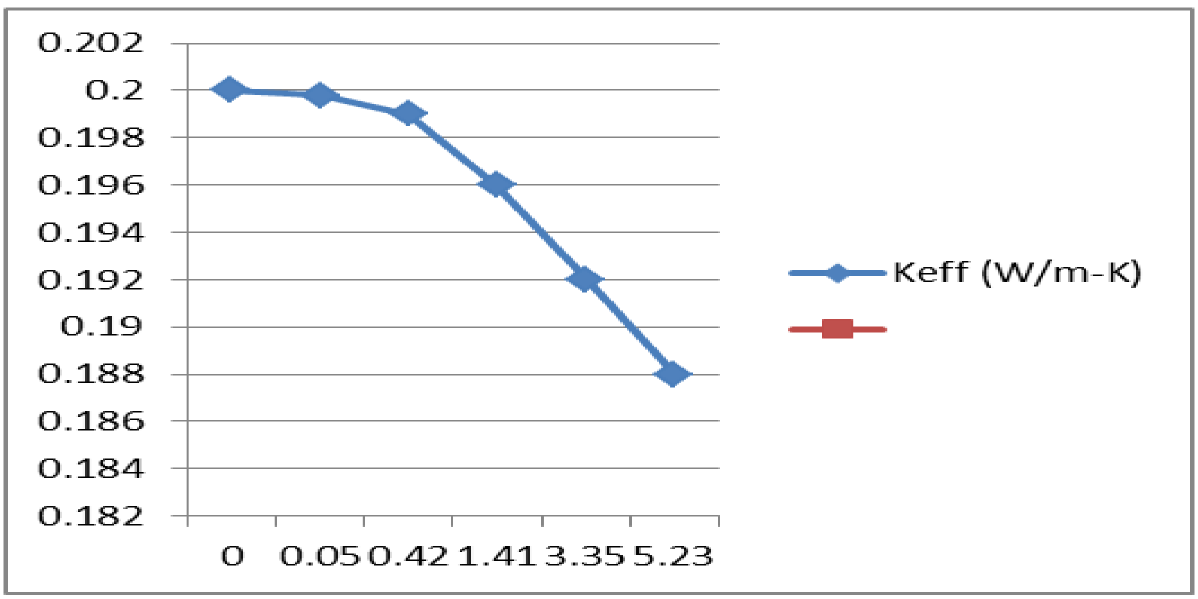
5.23% filler solid

Temperature counters of PP-SGM composites with fillers percentage



Vector field of temperature

SGM (vol %)	K_{eff} (W/m-K)
0	.2
.05	.1998
.42	.199
1.41	.196
3.35	.192
5.23	.188

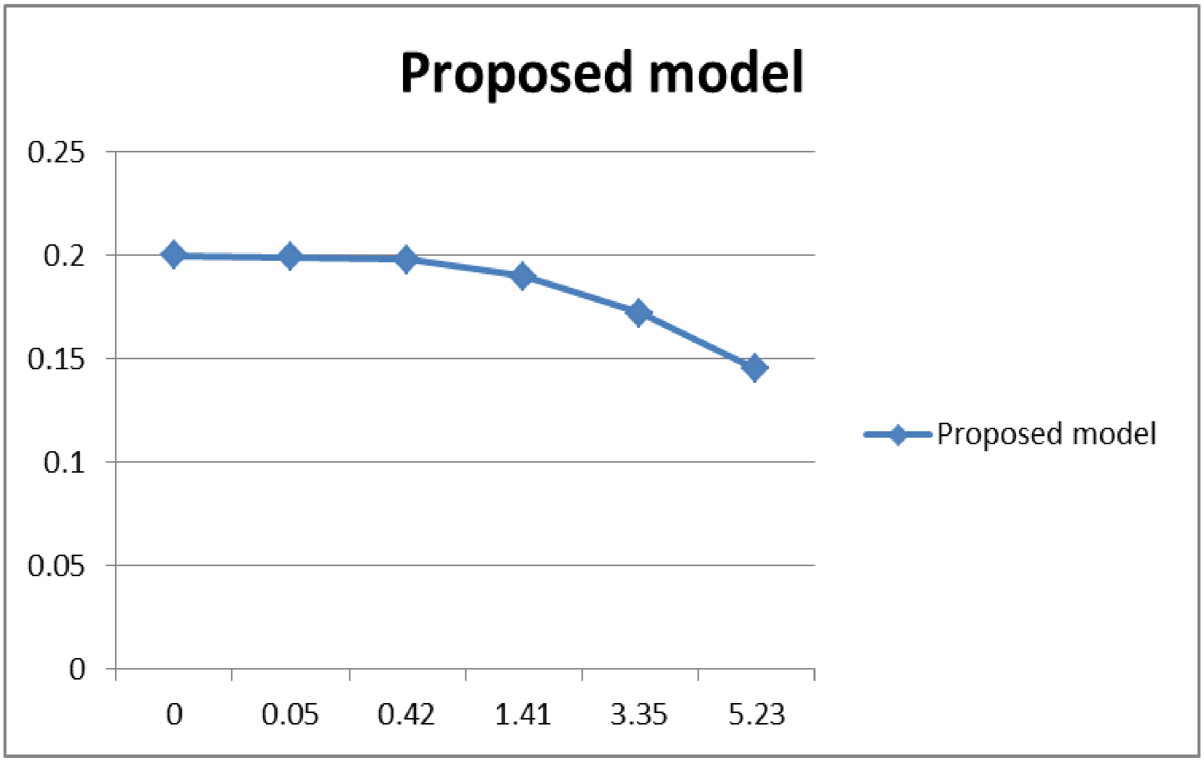


From the above fig. it is observed that the temperature variation between the top and bottom surface areas of the cubes increases with volume fraction percentage of the SGM. It is because of opposition of heat flow by the micro glass spheres along the conduction way.The above table and above fig. represent the variation of K_{eff} with SGM content in composites obtained from finite element method. It is noticed that, with increase in filler percentage in the composites, the value of K_{eff} decreases gradually. By addition of 5.23% of solid glass micro sphere, the net effective thermal conductivity of polypropylene composites decreased by 6% and by addition of 3.35% of SGM, thermal conductivity decreased by 4%.

Theoretical model for determination of effective thermal conductivity (K_{eff})

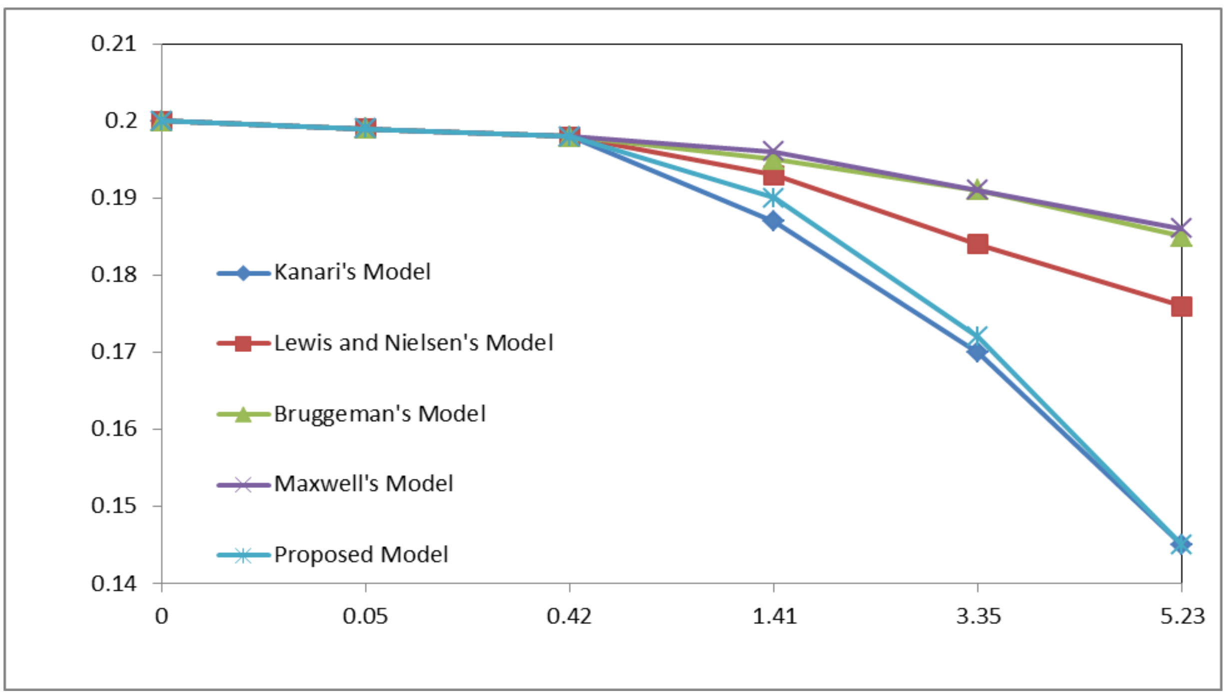
Below table represents the values of the net effective thermal conductivities (K_{eff}) of composites of PP- SGM obtained through proposed theoretical model with different volume percentage of SGM and results obtained through ANSYS by finite element model models.

$$K_{eff} = 1/\left(\frac{1}{Kp} - \frac{2}{Kp\sqrt[3]{(4\pi/3\emptyset f)}} + \frac{1}{\sqrt[3]{(4\pi/3\emptyset f)}}\left\{\frac{4rA}{KpVp+KfVf}\right\}\right)$$



By the help some existing theoretical models, I have calculated the effective thermal conductivity of polypropylene composites with SGM concentration varying from 0 to 5.23 vol. %. Then I compared the values of proposed analytical model with existing model.

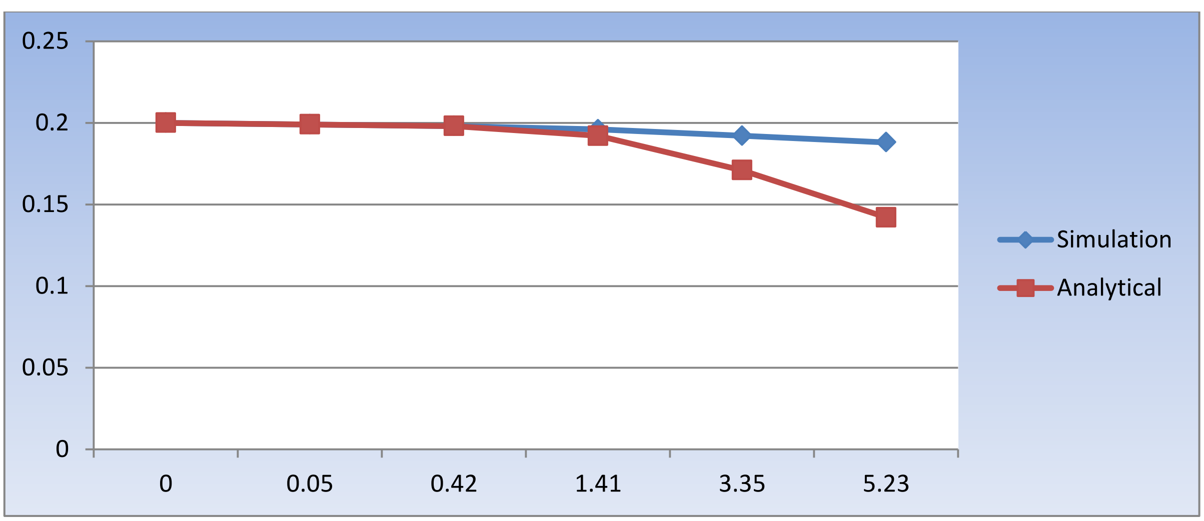
SGM Concentration (Vol %)	Maxwell's Model	Bruggmen's model	Lewis & Nielsen's model	Kanari's model	Proposed model
.05	.199	.199	.199	.199	.199
.42	.198	.198	.198	.198	.198
1.41	.196	.195	.193	.187	.19
3.35	.191	.191	.184	.17	.172
5.23	.186	.185	.176	.145	.145



From the above comparison, I found that the effective thermal conductivity of proposed model is fairly closed to Kanari's Model, which is revised of Bruggmen's model. Thus it is noticed that proposed mathematical model is a acceptable theoretical model for 1-D analysis of composite materials.

Below fig. represents the comparison of the net effective thermal conductivities (K_{eff}) results obtained through proposed theoretical model and results from FEM simulation of composites having different volume concentration. From the graph it is found out that the values of effective thermal conductivity of proposed theoretical model is fairly closed with the FEM model. But with higher percentage of SGM the FEM model deviates from proposed analytical model, because it is difficult to find the effective node in ANSYS due to course meshing.

SGM (Vol %)	Analytical Model	FEM Results
0	.2	.2
.05	.199	.1998
.42	.198	.199
1.41	.192	.196
3.35	.172	.192
5.23	.145	.188

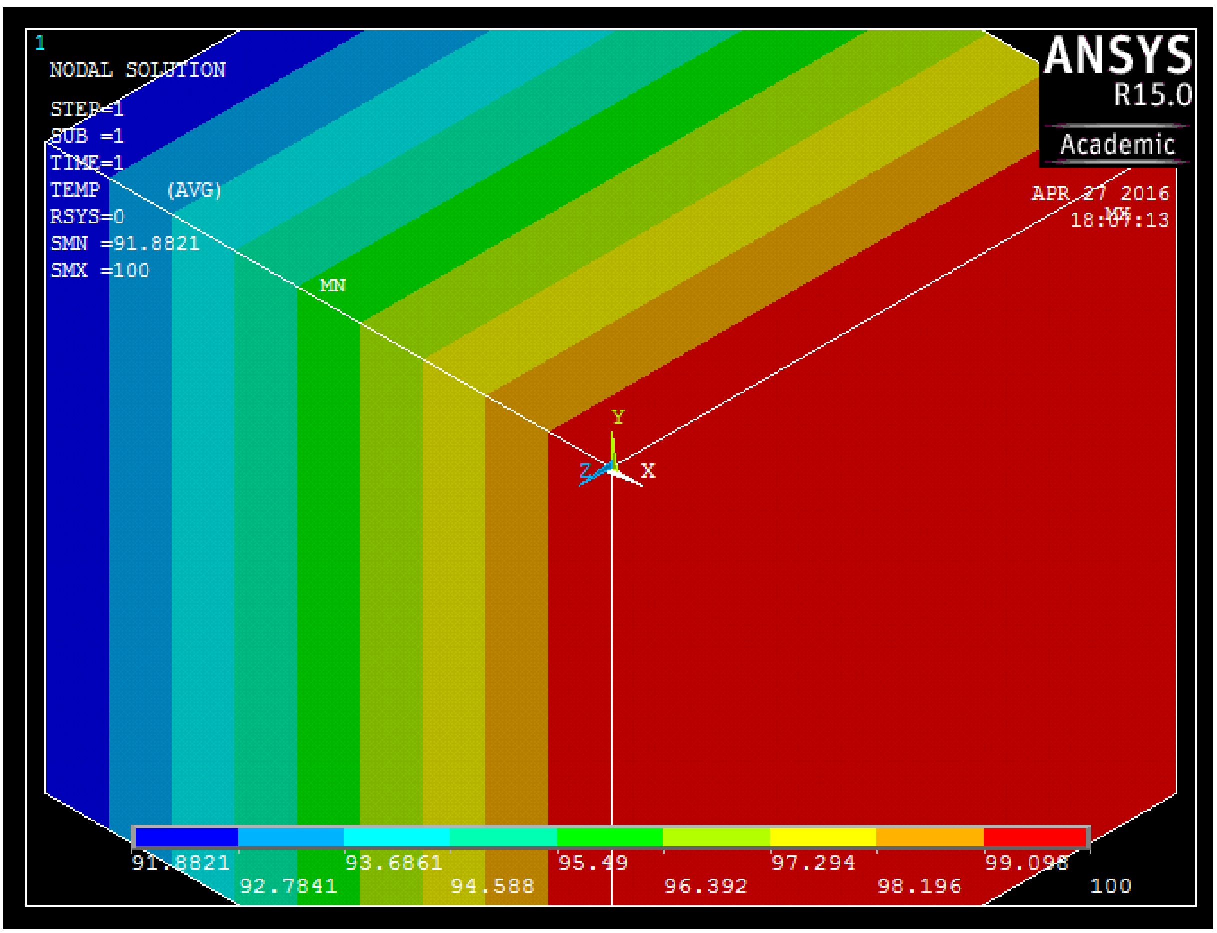


Polypropylene Composites mixed with Hollow glass micro- spheres (HGM)

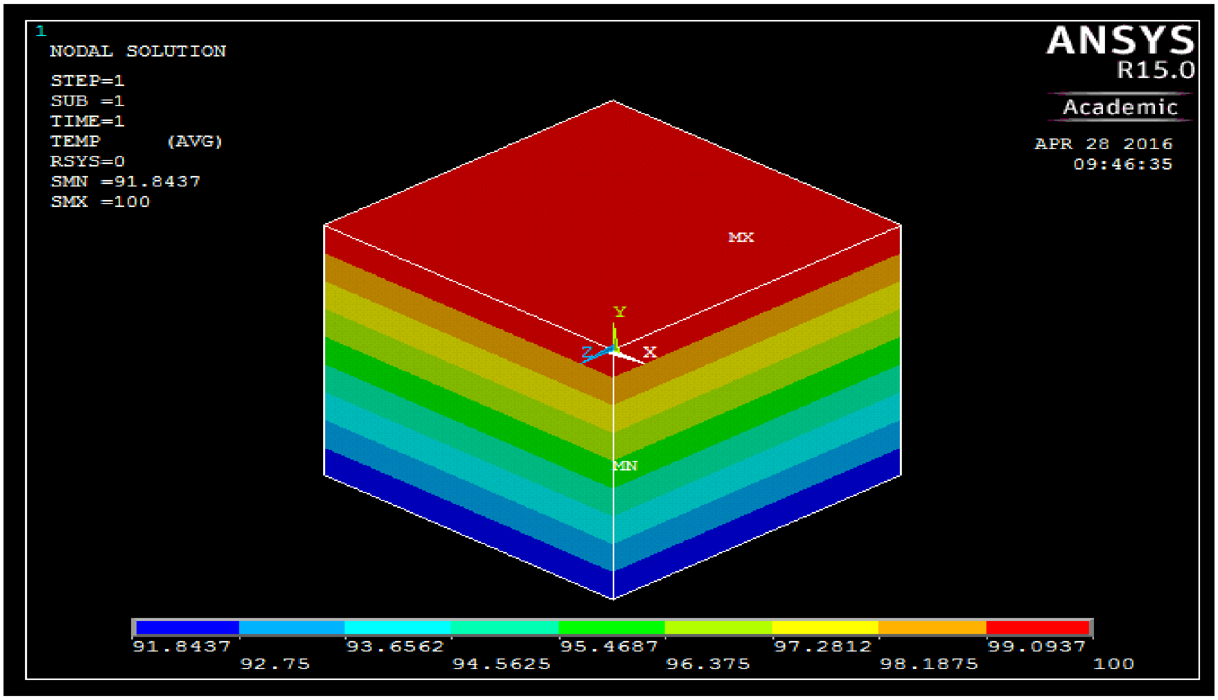
In this part I am presenting the values of effective thermal conductivity (K_{eff}) obtained through proposed analytical model and FEM simulation model for polypropylene composites mixed in different percentage of hollow glass micro-spheres.

Simulation Method

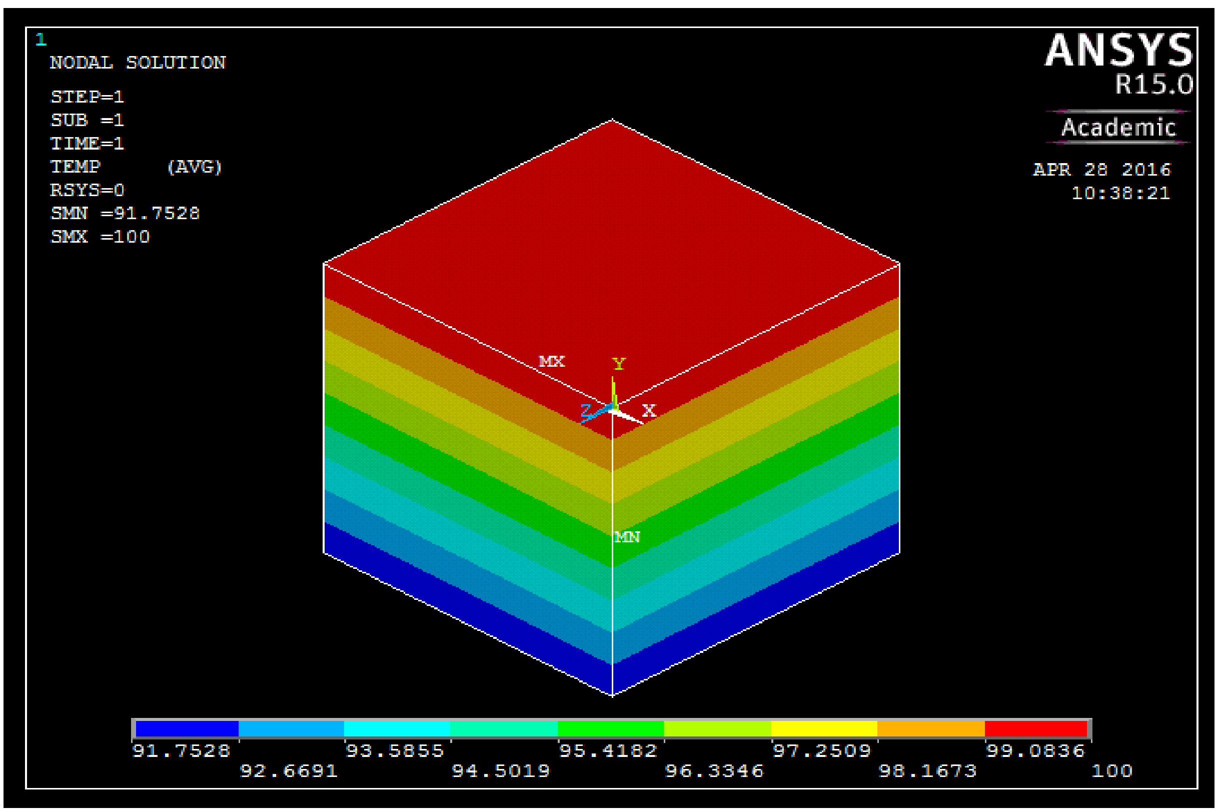
Here the finite element of ANSYS program is utilized for thermal analysis of conductive heat through polypropylene(PP)-HGM composites. For carry out this analysis,3- D models of the hollow spheres in cube (HGM in PP matrix) lattice array has been utilized to simulate the microstructure of PP-HGM composites of different concentration of hollow glass micro spheres. For these composites having hollow glass micro spheres concentrations of .05, .42, 1.41 and 3.35%, the temperature counters obtained from the FEM analysis is shown below.



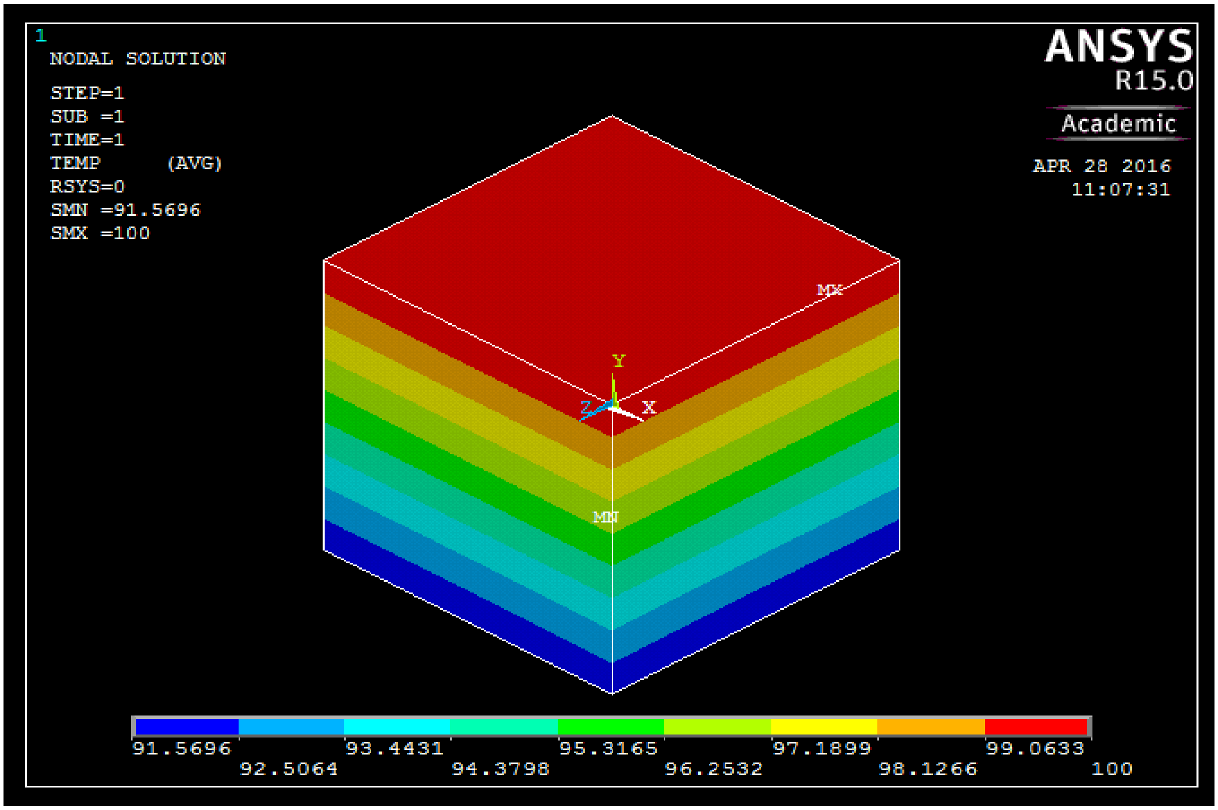
0.05% HGM concentration



0.42% HGM concentration



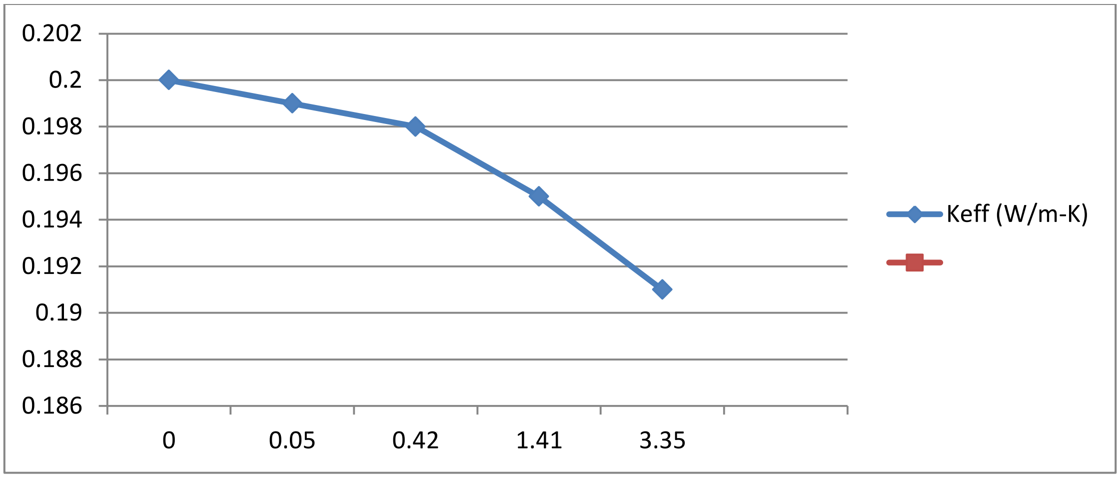
1.41 HGM concentration



3.35 HGM concentration

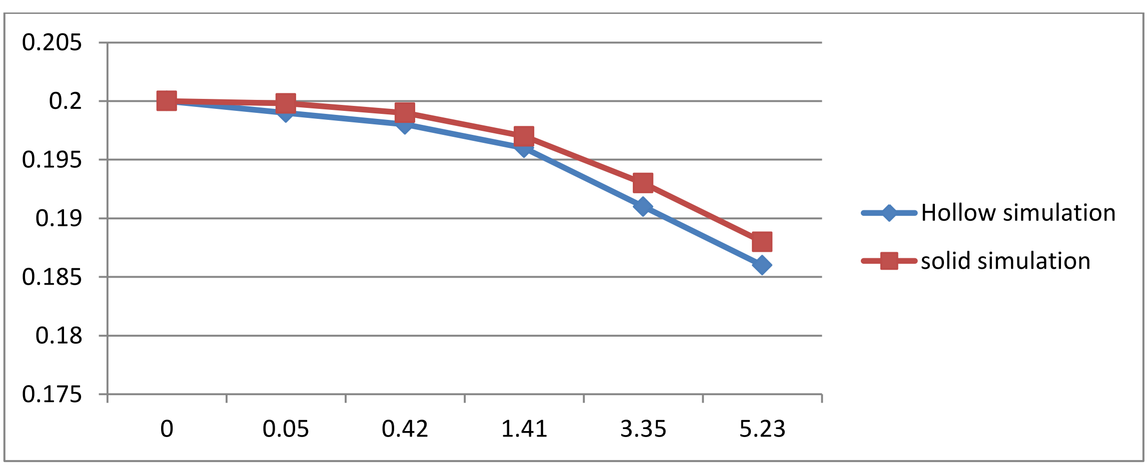
K_{eff} values of composites from FEM of HGM-PP composites

SGM (vol %)	K_{eff} (W/m-K)
0	.2
.05	.199
.42	.198
1.41	.195
3.35	.191



From the above fig. it is observed that the temperature changes between the top and bottom surfaces of the cube omposite increases with volume fraction percentage increase of the HGM. It is because of opposition of heat energy flow by micro-hollow glass spheres along conduction way. Due to hollowness of hollow glass spheres at the center there no heat conduction taking place at the center but radiation may take place, but as the operating temperature of polymer composite is around less than 100^0C, we can neglect the effect of radiation.

The above table and above fig. represent the variation of K_{eff} obtained from FEM with HGM concentration in composites. It is noticed that, with increase in reinforced filler percentage in polymer composites, the value of K_{eff} decreases gradually. And with addition of 3.35% of HGM, net effective thermal conductivity of polypropylene composites decreased by 4.5% but for SGM with addition of 3.35% of SGM, thermal conductivity decreased by 4%. So it is preferable to use hollow glass microspheres than the solid glass micro spheres, when we required high insulation and it also reduces the overall weight of component.



Analytical model for determination of net effective thermal conductivities (K_{eff}) of PP-HGM composites

Values of net effective thermal conductivities of above PP composites have been calculated analytically by using the Eqn. given below.

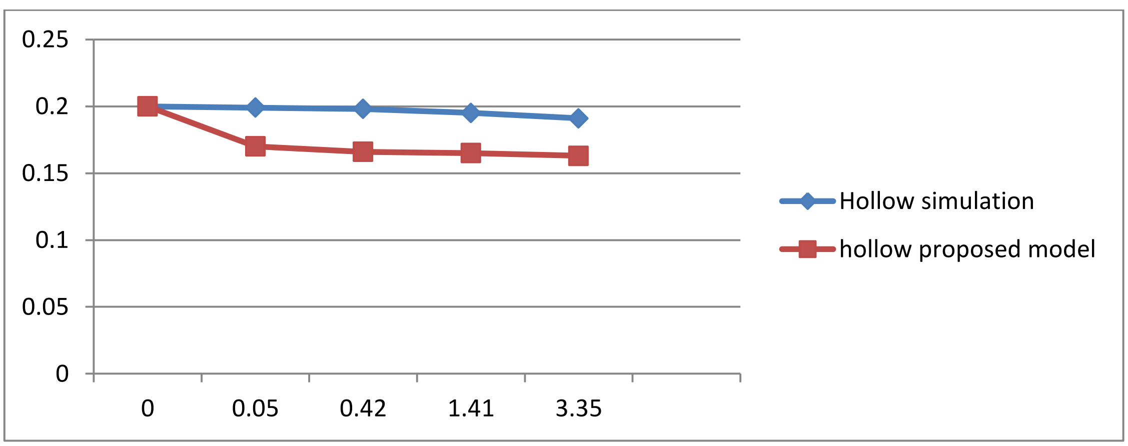
$$K_{eff} = H/\left(\frac{h1}{KpA} + \frac{h2^2}{KpVp+KfVf} + \frac{h1}{KpA}\right)A$$

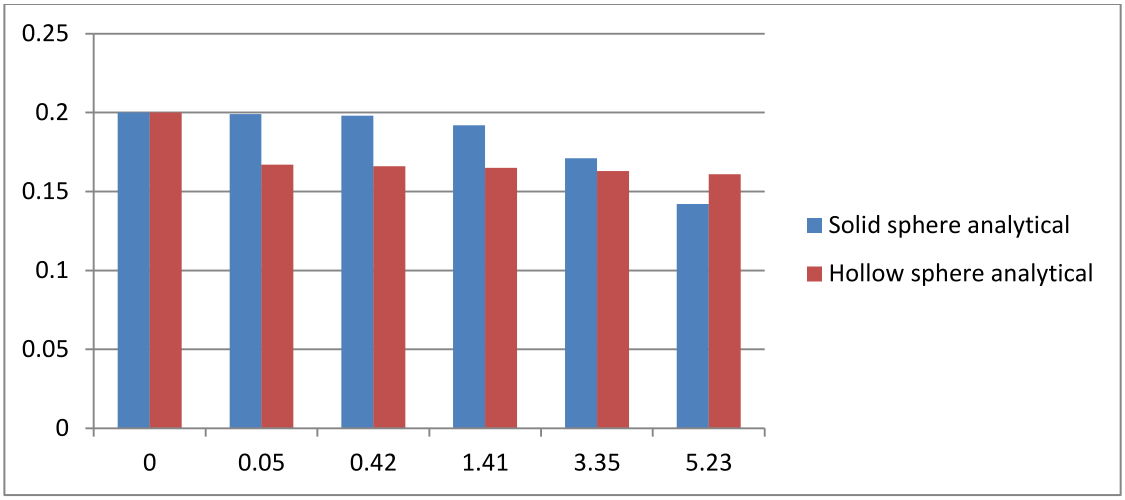
It is derived on one dimensional (1D) conduction model by integral approach. The assumptions that have taken to solve this Eqn. are

- Heat flows only one direction i.e. other four faces are insulated.
- There is vacuumed inside hollow portion of HGM.
- There is no radiation and convection inside the hollow portion of HGM.
- Both the boundary surfaces are at uniform temperature throughout the surfaces.
- Heat flows perpendicular to the surfaces.
- Composites are homogeneous in macroscopically.
- Both filler and matrix isotropic in locally.
- Contact resistance between matrix and filler material negleted.
- No void inside the composites is assumed.
- Uniformity in distribution of filler inside the matrix in a periodic manner.

Below table represents the values of net effective thermal conductivities (K_{eff}) of composites of PP- HGM obtained through proposed theoretical model with different volume percentage of HGM and results obtained through ANSYS by FEM model.

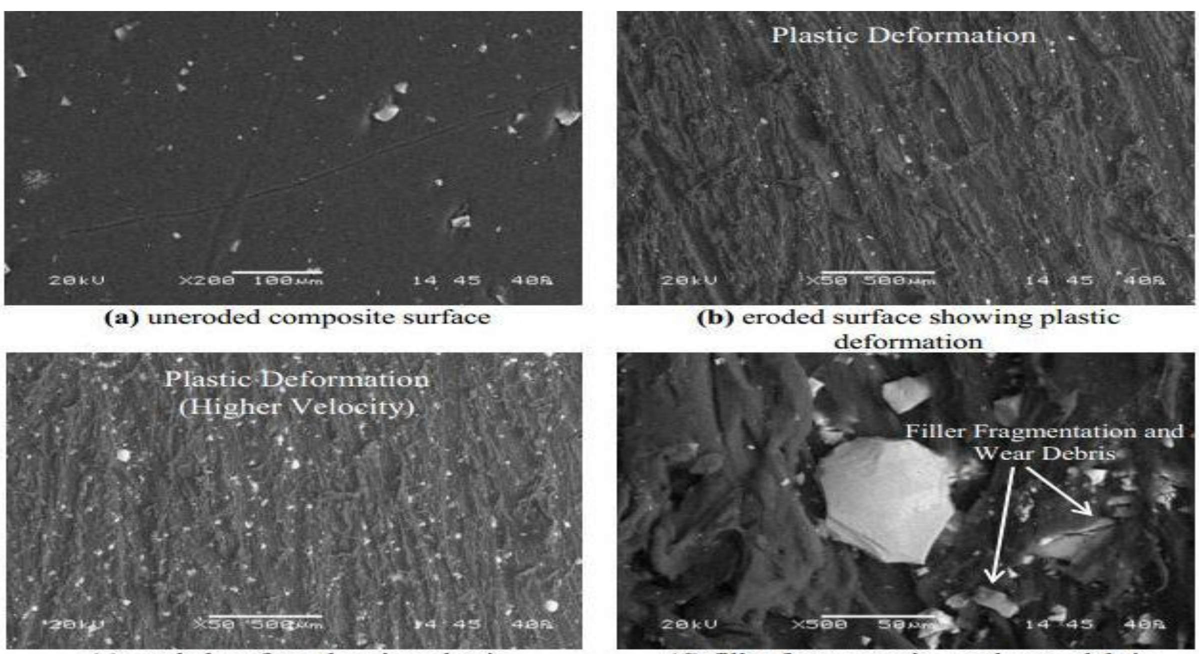
SGM (Vol %)	Analytical Model	FEM Results
0	.2	.2
.05	.167	.199
.42	.166	.198
1.41	.165	.195
3.35	.163	.191





From the above comparison, I found that the effective thermal conductivity of proposed model is fairly closed to FEM model, but at higher volume percentage concentration of filler there is deviation of proposed analytical model from FEM model, because to select all node points by fine meshing in FEM model is difficult. Thus it is noticed that proposed mathematical model is an acceptable theoretical model for 1-D analysis of composite materials.

Morphology of specimen



(a) uneroded composite surface

(b) eroded surface showing plastic deformation

(c) eroded surface showing plastic Deformation (at higher velocity)

(d) filler fragmentation and wear debris formation

SEM images of eroded and erodes surfaces

Chapter 5

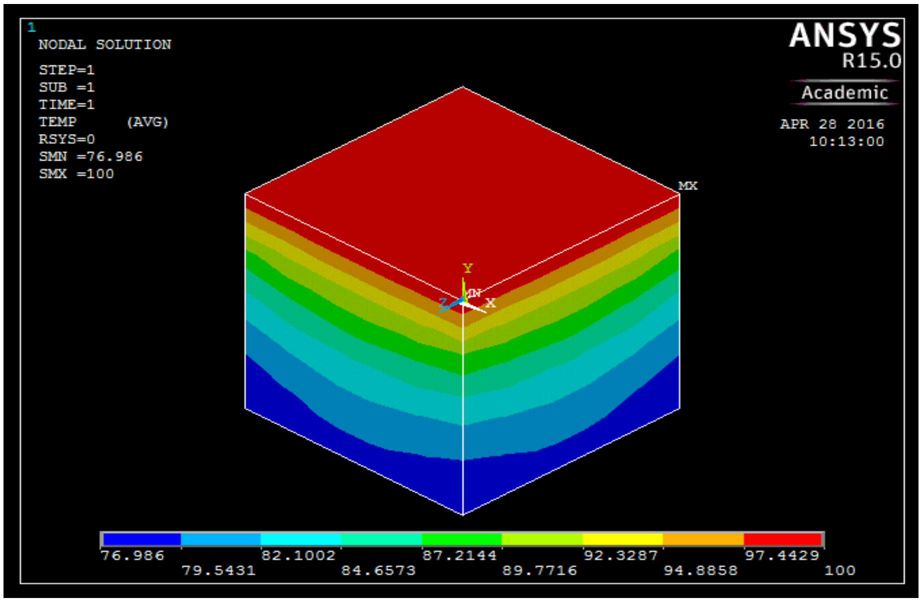
CONCLUSIONS

- For finding out the effective thermal conductivity (Keff), there are two theoretical correlations of solid glass microspheres (SGM) and hollow glass micro spheres (HGM) filled polymer composites are presented based on 1-D heat conduction models development. It is found out that, theoretical mathematical models represents as very good acceptable empirical models for the spherical (solid or hollow) inclusions and the derived relations from proposed mathematical models can be used very well to calculate Keff for composites.

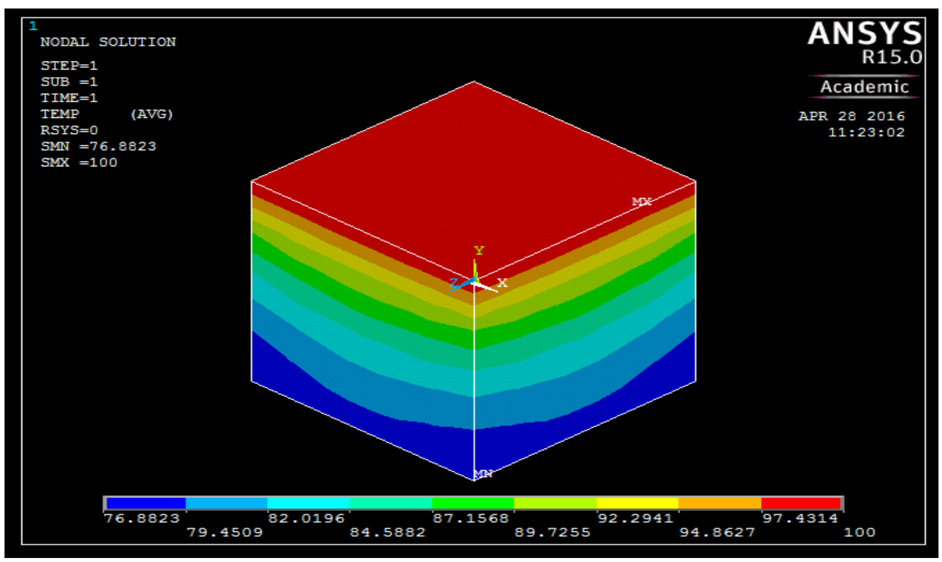
- It is propitious that, with addition of the SGM or HGM in PP matrix material, thermal insulation ability of polypropylene composites increases significantly. It is noticed that, with increase in reinforced filler HGM or SGM contents, the value of net effective thermal conductivities (Keff) decreases.

- With the addition of hollow glass micro spheres (HGM) in polypropylene composites the net effective thermal conductivities (Keff) of composites decreases more than the incorporation of solid glass micro spheres (SGM).

FUTURE SCOPE



4 filler solid 3D



4 filler hollow 3D

K_{eff} = .125 W/m-K (for solid)

To develop 3D analytical model by considering lattice structure, effect of voids, contact resistance between filler & matrix and considering reflection at the boundary of matrix & filler.

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